

The University of Chicago

UTILIZATION OF THE
ACOUSTIC REFLEX OF THE MUSCLES OF
THE MIDDLE EAR IN THE STUDY
OF BONE CONDUCTION

A PART OF A DISSERTATION SUBMITTED TO
THE FACULTY OF THE DIVISION OF THE
BIOLOGICAL SCIENCES IN CANDIDACY FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF PHYSIOLOGY

1937

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HEINRICH GUENTHER KOBRAK

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CHICAGO

In 1879, Hensen discovered that the tensor tympani muscle in a dog moves in response to stimulation of the animal's ear with sound. These reflex contractions of the tensor tympani muscle were studied later by Rockendahl, Pollak and others, and were again thoroughly tested by Kato in 1913. The use of the reflex as a method to test cochlear function in the animal has been developed only recently. In this country Lorente de No has published important observations using the reflex method in the rabbit.

The contractions of the middle ear muscles, as produced by acoustic stimuli, are simple reflex movements. The N. acusticus is the centripetal part of the reflex. Destruction of the cochlea or cutting of the eighth nerve abolishes the reflex immediately. The central part of the reflex has been experimentally located in the pons. The centrifugal branches are the N. trigeminus for the tensor tympani muscle and the facial nerve for the stapedius. Deep narcosis or death immediately abolishes the reflex. Either labyrinth may elicit the reflex.

The development of modern optical recording technic and the introduction of the electrical sound producer have made possible accurate quantitative measurements of the ratio between tone intensity and strength of contraction.

The slides demonstrate that tetanic contractions of both muscles are produced by a tone, and that the duration of the contraction depends on the length of the sound. When the camera opens there is always a certain click. Since the threshold of the stapedius and the

*I wish to acknowledge with thanks that the main part of this work has been carried out in collaboration with Dr. J. R. Lindsay and Dr. H. B. Perlman. I also wish to thank the Sonotone Company for furnishing one of their instruments for use in the animal experiments.

tensor are different, only the more sensitive stapedius reacts to this click. Since the click sound of the camera is always the same intensity and the reaction of the stapedius is equally constant, this furnishes a further proof that equal acoustic stimulations produce equal amounts of contraction.

Any increase of the intensity of the tone is followed by a parallel increase of the muscle contraction. The threshold of the muscle contraction is higher than the threshold of hearing. However, the threshold is not as high as some authors believe, provided certain mistakes are avoided. The fact that the click of the camera elicits a reflex movement speaks for itself.

So far as the mechanical function of the contractions are concerned, several theories have been advanced. The majority of investigators favor the protection theory. However, the accommodation theory and other opinions still have active defenders. The mechanism of the contractions apparently consists in the diminution of the amplitude of the vibrations of the ossicular chain and of the labyrinthine fluid. This effect is, so far as the tensor is concerned, very conspicuous and was demonstrated several decades ago. The errors which the lever method of the early investigators necessarily entails can be avoided by using optical recording. For the routine experiment it is easier not to record the contractions but simply to observe them. The method is very simple. The bulla is opened on its ventral side. A 15-diopter lens provides a suitable enlargement of the tensor. The observer determines the intensity of a tone which gives a threshold contraction of the tensor. The readings are taken for different pitches and the results plotted like audiometer curves. The threshold contractions of the tensor are very definite and various observers do not differ more in their readings than do audiometer tests in the clinic.

The rabbit is kept in superficial general anesthesia. Dealing with a reflex, the question of anesthesia is a very important one. The curve taken on an animal under local anesthesia, compared with the average threshold reading for sixty normal rabbits under urethane anesthesia demonstrates that with this type of narcosis there is hardly any interference with the reflex movements. The tensor contractions may be observed continuously over a period of several days provided aseptic precautions are taken.

One of the greatest assets of the optical method is the fact that the reflex can be observed in the human. The contractions of the stapedius muscle in the human were first seen by Lüscher, who ob-

served the tendon with his special otoscope. The number of patients who have a perforation in the posterior half of the drum that permits observation of the stapes or the stapedius tendon is not small: we have seen about thirty cases during the last year in the University of Chicago clinics. In some of these patients the movements of the stapes was recorded by means of a moving picture film (Demonstration).

The reflex works in the same way for bone conduction. As a sound source the audiometer connected with a bone conduction receiver has been used. In the animal experiment the receiver was placed on the teeth, in the human usually over the mastoid process.

The value of the reflex contractions of the middle ear muscles, as an objective means to determine cochlear function, may be summarized briefly as follows:

1. In the rabbit the two muscles of the middle ear contract regularly in the presence of a tone of a certain intensity and frequency. The contractions begin and end accurately with the tone.
2. The reflex is elicited by both air and bone conducted sounds.
3. The ratio between the intensity of the sound and the strength of contraction is definite. Increase or decrease of intensity is followed by parallel changes in the muscle contraction.
4. The threshold for the muscle contractions, determined by observation with a lens, is higher than that for hearing.
5. Low and high tones are less effective than the middle range frequencies in producing these reflex contractions.
6. In man reflex contractions of the stapedius muscle can be observed, which show nearly identical properties as found in the animal: Numerous comparisons between reflex activity and hearing sensations can be made.

FUNCTIONAL CHANGES DUE TO MIDDLE EAR LESIONS

The following lesions of the sound conduction apparatus have been produced in the experimental animal: (1) Plugging of the outer acoustic canal representing the conditions in man with cerumen obturans. (2) Filling the bulla with fluid, thus simulating middle ear catarrh. (3) Partial destruction of the ossicular chain; for in-

stance, perforation of the eardrum, destruction of the incudostapedial junction, luxation or extirpation of the incus, thus producing conditions comparable to those in some patients with chronic suppurative middle ear lesions. Some of these procedures have the advantage of being reversible, in that a record can be taken not only before the lesion has been produced, but rechecked after removal of the lesion. Its importance is evident if only slight changes are expected. The ability to repeat the observations assures results which otherwise would not be reliable.

In the study of the Rinne test in the animal the threshold for contraction of the middle ear muscles for air conduction was taken first and then the threshold for bone conduction. Since the sound producing apparatus for air conduction and bone conduction is not the same, we cannot compare the two thresholds from the quantitative standpoint. But this is also true in the clinical Rinne test, where the prongs and the stem of the tuning fork are different sound producers with different physical qualities. Having determined the normal thresholds, if one produces lesions of the sound conduction system, the hearing for air conduction goes down or even disappears entirely. At the same time the hearing for bone conduction does not show any impairment, but is even improved to some extent. Our experiments show that these functional changes take place regardless of the nature of the lesion to the conductive apparatus. The plug in the outer acoustic meatus has the same influence as the destruction of the ossicles or the instillation of fluid into the middle ear. However, the degree of change may be different; in some instances, the air conduction is absolutely lost for intensities produced by our apparatus. Plugging of the outer canal produces only a minor impairment. These experiments illustrate that the conditions of the Rinne test may be observed in the animal. Lesions of the sound conducting apparatus create conditions which alter the normal proportion between air and bone conduction so that finally the bone conduction may be better than the air conduction. Lesions of the inner ear diminish or abolish the function for air and bone conducted sounds alike.

The Weber test cannot be carried out experimentally in the animal for the following reasons: the middle ear muscle reflex in either ear is produced almost equally by either labyrinth. Besides this physiological reason there is a psychological reason, which involves the very nature of the Weber test. The fact that a patient lateralizes to one ear does not mean that he has no acoustic irritation in the other ear. The sensation is shifted into the one ear, due to a

psychologic effect, while the appreciation of the acoustic stimulus in the other ear is suppressed. Under these conditions hearing sensation and acoustic irritation are dissociated, and the middle ear muscle reflex fails to be a true picture of the hearing sensation.

The experimental procedure for the Schwabach test in the animal is similar to that used for the Rinne test. The readings of the tensor are made before and after the lesion has been produced.

In this country evidence has been presented which seems to indicate that an absolute increase in bone conduction does not exist. It has been assumed that in making tests on bone conduction in a room which is not soundproof, the noise of the environment has a marked influence on the results. Our experiments show that the threshold for bone conducted sound is slightly but definitely lowered after lesions in the middle ear. For practical purposes it may be sufficient to do clinical tests in a soundproof room and to omit any discussion whether or not there is an additional real increase in bone conduction which is not explainable by the masking effect. If, however, we wish to understand the problem of bone conduction, we cannot discard this experimental finding, even if the difference is minute from the quantitative standpoint. The animal experiment in which the cochlear function can be measured reliably seems to furnish a new way of approach. Since we observed a stronger reflex contraction after the middle ear lesion had been made, the most obvious explanation is that the irritation in the inner ear was slightly greater than before.

EXPERIMENTS ON MASKING

In this series of experiments the influence of a masking tone on the contractions of the tensor tympani muscle produced by bone conducted sounds has been studied. The work has been done in collaboration with Dr. Elisabeth Huff.

Both pure tones and noise were used as masking sounds. We found two distinctly different results according to the intensity of the masking tone. If the masking tone is above the tensor threshold, the tensor is in a stage of contraction so long as the masking tone lasts, and the primary tone produces superimposed contractions. In this case the determination of the superimposed contractions cannot be made accurately. Because of this interference with the muscle itself, we discarded loud masking tones and confined the intensity of the masking tones to under-threshold values.

If the masking tone is below the tensor threshold there is no appreciable change in the contractions due to the primary tone. Observations were made on human beings, employing the same frequencies and intensities as were used in the animal experiments. As was to be expected, a typical masking effect was obtained. A tone that is distinctly effective for masking in the human does not interfere with the tensor tympani reflex. The conclusion may be drawn, therefore, that the centripetal impulse originating in the cochlea and determining the strength of the tensor contraction is the same, regardless of the presence or absence of a masking tone. The stapedius reflex observed in man corroborates the findings of the animal experiment. There was no noticeable change in the stapedius contractions due to a bone conducted sound when a masking tone was introduced. Needless to say that the hearing sensation showed a typical masking effect when tested with the same masking tone. Incidentally electrical experiments by Davis and Saul gave a similar result. The cochlear potentials picked up at the round window did not show interference by masking. The phenomenon of masking apparently is not located in the peripheral sense organ.

FUNCTIONAL CHANGES DUE TO LOSS OF LABYRINTHINE FLUID

If a very fine hole is drilled in the apical part of the cochlea of the rabbit an increasing functional impairment is observed as the labyrinthine fluid escapes. The effect is about equal for bone and air conduction. If the drill-hole is allowed to heal, one can observe some remaining function, since the inner ear apparently is now under more favorable hydrostatic conditions. Briefly this series of experiments suggests that the labyrinthine fluid is an essential part for the cochlear function and is equally important for air and bone conducted sounds.

FUNCTIONAL CHANGES DUE TO EXTIRPATION OF THE STAPES

Experiments have been carried out in which the stapes was destroyed or extirpated in the rabbit and the functional changes for bone conducted sounds observed. If one destroys the crura of the stapes there is no loss of bone conduction. The destruction of the stapes footplate of course opens the labyrinthine fluid system. A gush of fluid escaping from the oval window indicates the successful destruction of the stapes footplate. Now a piece of cotton must be inserted immediately. With this method it is possible to prevent a too severe loss of labyrinthine fluid. The result has been that cochlear function can be demonstrated for bone conducted sounds, even in the absence of the stapes.

FUNCTIONAL TESTS AFTER PLUGGING OF BOTH WINDOWS

Both the oval and round window were plugged with plaster of Paris and the resulting cochlear function determined. No cochlear function could be demonstrated, by either air or bone conducted sounds, after such blocking.

DISCUSSION

The three series of experiments were carried out with the purpose of obtaining information regarding the pathways of bone conducted sounds on their way to the organ of Corti.

The experiments on the middle ear indicate that good bone conduction is compatible with complete absence of the ossicular chain (drum, malleus, incus and the crura of the stapes). The additional destruction of the stapes footplate causes a definite drop in bone conduction. The result is explainable by the loss of labyrinthine fluid. It was experimentally impossible to determine the isolated effect of the stapes footplate on bone conduction. Bezold's opinion that the bone conducted sound can enter the labyrinth only via the stapes has not been corroborated by these experiments. Apparently cochlear irritation by bone conducted sounds is possible in the absence of the complete ossicular chain.

The escape of intralabyrinthine fluid is associated with a severe loss of cochlear function. Intralabyrinthine fluid is vital for cochlear function as tested by either air or bone conducted sounds.

A possible explanation for the absence of cochlear function when both windows were solidly fixed by plaster of Paris is that the aqueductus cochleæ and the related lymphatic craniolabyrinthine communications possess a too great resistance to act as a third window and permit displacement of fluid. The experiments therefore seem to corroborate the teaching of Rejto and Herzog, that bone conducted sound produces rhythmical vibrations of the otic capsule. These vibrations irritate the end organ identically as it is irritated by air conducted sounds.

